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By

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United States Department of Agriculture

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INTRODUCTION

The purpose of this bulletin is to indicate improvements in the irrigation of citrus orchards, as suggested by the results of investigations in southern California by the Bureau of Agricultural Engineering.[1] In these investigations, amounts of water transpired were determined by intensive soil sampling; average seasonal transpiration use of water by mature citrus trees was established as a proportion of average seasonal evaporation, and the amounts of water which must be supplied by irrigation during an average season were ascertained. A study of water-company and packing-house records to find the relation of use of water to yield of fruit was made. At the same time, information was obtained regarding the effect of soil type on use of water and on yields. During 1936, field studies were made to determine the degree of water deficits developed in the trees under present practices and the effect of length of irrigation runs on size of fruit. Measurements were also made of absorption of water in furrows and of plow sole conditions in orchards. In this bulletin the bearing of each of these phases of orchard industry on the general problem of water economy is discussed

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1/ The information in this bulletin has been gathered from a number of sources with the help of several agencies. Since 1925 the Division of Irrigation of the Bureau of Agricultural Engineering has been conducting research studies on consumptive use of water by native vegetation and crop plants in southern California. In portions of the work the University of California has participated; in other portions the Division of Water Resources of the California State Department of Public Works has been a cooperator. In 1932 active cooperation was initiated with the Division of Fruit and Vegetable Crops and Diseases of the Bureau of Plant Industry for the conduct of further research into the water relations of citrus trees. These works have been reported upon from time to time in bulletins of the Department of Agriculture and its California cooperators.

Early in 1936 a cooperation was started under the sponsorship of the Agricultural Extension Service of Los Angeles County. Labor was made available by the Works Progress Administration for a survey and statistical study of irrigation problems in citrus orchards. The resulting material obtained under official projects numbers 65-3-3112 and 165-03-6999, and other supporting data, have been brought together in this bulletin.

Data on seasonal use of water and evaporation were obtained in cooperation with the Division of Water Resources of the State of California Department of Public Works.

and methods for improvement are outlined. The field work was done in the eastern part of Los Angeles County and the western part of San Bernardino County, Calif. However, the underlying principles involved have general application and there are analogous conditions in other districts. The suggested methods for improvement are applicable to a wide variety of orchard conditions.

Because of the value of citrus property and the investment required to bring trees into production, higher expense may be justified for controlling their irrigation than that of many other types of growth. Large expenditures have been made in developing necessary water supplies and delivering them to orchard units with the minimum loss in transit. Further economies rest largely with those who direct the application of water to the land. To secure the best results, growers should have a thorough understanding of the manner in which water is used by orchard trees, the effect of seasonal weather conditions, and the factors involved in maintaining a satisfactory supply of available soil moisture.

Extreme variations in methods of irrigation and related cultural practices may be found in citrus orchards, and these should all be considered from the standpoint of efficiency and economy in maintaining the necessary moisture supply within the root zone. Both applications of organic matter and the growth of winter cover crops improve the physical condition of the soil and affect the rate at which water enters the soil. Volunteer cover or weed growth during the summer has a similar influence on infiltration, but must be kept under control because of competition with the trees. Methods of cultivation for weed control and preparation of the land for irrigation may be greatly improved in most orchards, and the over-all efficiency of irrigation will be raised thereby. Improved methods are outlined in the latter part of this bulletin and suggestions are offered by the use of which cultural costs may be reduced.

TRANSPIRATION REQUIREMENTS AND CLIMATIC INFLUENCES

Most of the work reported in this bulletin was done in a climatic zone which is classed as intermediate between the areas under a coastal influence and those of the more arid interior. Weather conditions in this area are indicated in figure 1, which sets out the seasonal trend of maximum and minimum temperatures for the 5-year period 1932 to 1936, inclusive. The average evaporation from a free-water surface in a shallow black pan[2/] is also shown for the same period.

Comparison of the curve representing evaporation with that representing maximum temperature reveals a similarity. Seasonal water requirements of citrus trees may be expected to follow a like

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2/ For a detailed description of the evaporimeter see: Blaney, H. F., "Consumptive Use of Water By Native Plants Growing In Moist Areas In Southern California." Calif. Dept. of Public Works, Div. of Water Resources Bull. No. 44, pp. 97-99, illus.

trend, as is brought out in figure 2. In part of this figure, the variation in transpiration-use of water by a plot of mature navel orange trees is shown. This information was obtained from intensive soil-moisture studies in which the amount of water extracted from the soil by roots and used in the trees or lost by transpiration from the leaves was termed transpiration-use. Similar work was done at different times during the period 1928 to 1937 on 10 citrus plots in the eastern part of Los Angeles County and the western part of San Bernardino County. These results have been expressed as a ratio between transpiration-use of water and evaporation, the average being 0.33. In other words, the average loss of water from mature citrus trees by transpiration was determined to be one-third of the evaporation from a free-water surface in a shallow black pan. This is brought out in figure 2, the values given being expressed in equivalent inches of depth per month; that is, for an orchard area, transpiration-use is expressed as the equivalent depth of water in inches over the area considered. The total annual evaporation from the shallow black pan averaged 72 inches, and the indicated annual transpiration of mature citrus trees in this intermediate climatic zone is 24 inches.3/ Losses by evaporation from the ground surface or use of water by cover crops are not included in this value.

During the winter months moisture from rainfall may be expected to take care of the needs of the trees. The average rainy season begins late in November and lasts a little over four months. Seasonal variations in rainfall at Glendora are shown in figure 3. Ordinarily the soil is filled to field capacity after the last effective spring rain, and when this supply of moisture has been depleted irrigation must be relied upon until the next effective rain comes in the fall. The period between the last effective spring rain and the first effective fall rain is shown for each year in figure 3.4/ The average for the 55-year period from 1883 to 1937, inclusive, is 232 days.

3/ Use of water by citrus and avocado trees in San Diego County, Calif. is reported by Beckett, Blaney, and Taylor. Beckett also reports on the use of water by citrus trees in the coastal areas of Orange and Los Angeles counties and the interior areas of Riverside and San Bernardino counties. See: Beckett, S. H., Blaney, H. F., and Taylor, C. A., "Irrigation Water Requirement Studies of Citrus and Avocado Trees in San Diego County, California, 1926 and 1927," Calif. Agr. Expt. Sta. Bull. 489, 51 pp., illus., 1930; also, Beckett, S. H., "Irrigation Requirement Studies in Southern California," Calif. Dept. of Public Works, Div. of Water Resources Bull. No. 32, pp. 57-60.

4/ The terms "last effective spring rain" and "first effective fall rain" are used rather loosely and cannot be defined with precision. The aim has been to get some measure of the length of the dry season. The time of the last spring rain, when the soil was filled with moisture to about its field capacity, was used as the time of the last effective spring rain. Rain in amount sufficient to terminate the regular irrigation season was considered as the first effective fall rain. The term "field capacity" designates a soil-moisture condition ordinarily found within a few days after rain or irrigation has thoroughly moistened the soil and rapid drainage has ceased.

A study of figure 3 reveals that usually the rainy season ends sometime between March 10 and May 10, the average date being April 9. Extremes occurred in 1884 and 1894. In 1884 the rainy season ended June 12, while in 1894 it ended January 18. These variations are brought out graphically in figure 4.

The first effective fall rain came during the last week in September in three years of the 55, but there were years when no effective rains fell until February or March. November 27 was the general average date for the first effective fall rain. From a study of figure 4 it may be determined that the chance is only about 1 in 4 that rain will fall in sufficient amount to end the irrigation season prior to November 1. Distribution of fall rains is so variable that the odds are against the grower who defers irrigating and gambles on the occurrence of rain. Therefore, regular irrigations should be continued each year until effective rains have actually fallen.

For the average season, a period of 232 days elapses between the last effective spring rain and the first effective fall rain. Variations in the total seasonal evaporation during these dry periods were determined, and most dry seasons were found to lie within the range from 50 to 60 inches of evaporation. The average for all seasons was 55 inches. If this value (55 inches) be multiplied by the factor 0.33, a resultant of 18 inches is obtained as the average seasonal transpiration requirement for mature citrus trees during the dry season. Not all this 18-inch transpiration requirement need come from irrigation, as a certain amount of storage holds over from winter rains. This storage may be equivalent to 3 inches on the sandier soil types, or as much as 5 inches on the deep medium sandy loam soils, depending on the root distribution as well as the soil type and cover-cropping practices. The problem of the grower is to keep an adequate supply of moisture within the root zone during the summer months after this stored rainfall has been used.

After the trees have used the 3 to 5 inches of moisture stored in the soil from winter rains, further withdrawals will depend on the supply made available through irrigation. For mature trees, the equivalent of from 13 to 15 inches of water must come from this source. In order to place 13 to 15 inches of moisture within the root zone during the course of an irrigation season, many growers find it necessary to apply as much as 26 inches of water or more on the ground surface. Certain losses by evaporation are unavoidable, and run-off and percolation below the root zone also occur. Efficient irrigators reduce these losses to a minimum. Others, less successful, apply much water that either runs off or percolates below the root zone. Hence, relative efficiencies of different practices, as well as differences in the needs of the trees, influence the results obtained from the application of different amounts of water. These factors bear on the relation of yields to amounts of water applied, which is discussed in the following pages.

USE OF WATER AND YIELD OF FRUIT

Records of two of the mutual irrigation companies serving 5,000 acres of citrus orchards in the eastern part of Los Angeles County were examined to determine whether there was a relation between the amount of water used and the yield of fruit. These orchards are practically all mature, the age of the trees ranging mostly from 20 to 50 years. Plantings of Washington navel orange trees predominate in this area and production records were obtained for 46,630 navel orange trees, 32,420 Valencia orange trees, and 29,850 lemon trees. In all cases the average annual production for the 6-year period from 1931 to 1936 was compared to the average annual amount of irrigation water applied during the same period. These records represent the practical experience of farmers in this area and give a measure of the success they have had in the business of producing citrus fruits.

The analysis presents records of all accounts for which complete 6-year data were available. Water applied on some orchards amounted to only 14 inches per year, while in other cases it averaged nearly 36 inches per year. The yield from most orchards was covered by a range of 1 to 8 field boxes per tree. Vaile[5/], from a study made in 1922, reported that lemon production per acre was considerably higher than that for oranges, and at first it was intended that a separation be made between navel and Valencia oranges and lemons in this study. However, it was found that in this particular area there were many mixed plantings and no material differences in the practices used for these crops. The average navel orange yield per tree was slightly higher than the average lemon yield, and the average Valencia yield somewhat lower than the average lemon yield. For the purpose of this study all varieties were included and no separations were made.

Orchards were separated into groups according to yields as follows: (1) a marginal group of orchards with yields of only 1 to 3 field boxes per tree, (2) a group with yields of from 3 to 5 field boxes per tree, (3) a group with yields of from 5 to 7 field boxes per tree, and (4) a high-yield group with a production of over 7 field boxes per tree.[6/] The numbers of orchards in these various groups are shown in figure 5. It appears that there is a consider-

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5/ Vaile, R. S. "A Survey of Orchard Practices in the Citrus Industry of Southern California." Calif. Agr. Expt. Sta. Bull. 374, 40 pp., illus., 1924.

6/ The weight of fruit in one field box is 48 pounds for lemons, 52 pounds for navel oranges, and 55 pounds for Valencia oranges at the packing houses through which most of the fruit was shipped. For orchards with average tree spacing in this area, a yield of 7 field boxes per tree is equivalent to approximately 600 field boxes per acre, or 400 packed boxes per acre.

able range in the amounts of water used by each group, but the averages are progressively higher for the orchards with higher yields. The average use of water by the marginal group with low yields was 20.1 inches per year, while for the group with the highest yields it was 25.7 inches per year. Relatively few orchards yielded over 7 field boxes per tree, but it is worthy of note that some growers secured this production with remarkably little water.

In order to bring out the effect of increasing use of water on yield, the orchards were arranged in groups according to amounts of water applied. The result of this grouping is shown in figure 6. In this figure the numbers of orchards falling within the different water-use classes are arranged according to yield. It is apparent that the average yield of the two lowest groups of water-users shown at the bottom of the figure was definitely low. The highest average yield was shown by the group using 24 to 28 inches of water. The use of larger amounts of water did not, on the average, return higher yields, and production on the orchards using more than 32 inches of water was definitely lower.

Conclusions from this evidence should not be drawn too definitely. Many factors other than water will affect yields; for example, nitrate fertilization has a positive influence. The significant point is that in the analysis of the data certain trends may be observed that are definite enough to show a significant correlation in spite of other influences. In 1922 Vaile[7/] noted a similar trend of decreasing yields for the highest water-users in the coastal areas. He found, however, that the greatest production came from heavily irrigated orchards in the intermediate climatic zone, but reported evidence of decline in some of the more heavily irrigated orchards. Wahlberg[8/] reported in the Valencia production cost study in Orange County that most of the high-profit orchards used 16 to 20 inches of water per year. This represents a conservative use for the coastal area and checks with Vaile's findings.

In the course of field observations on heavily irrigated orchards, root distribution has been observed by the writer in trenches that were dug across irrigation furrows. Where excessive water had been applied on coarse soils, very few roots were found in the soil under the furrows. More feeder roots were observed in the soil where the water had moved out laterally from the furrows toward the dry tree line. The soil directly under the furrows which had been leached by excessive irrigations did not offer the most favorable conditions for root growth. Orchards receiving excessive irrigations not only have to stand the added cost of water but also the the loss of nitrogen carried beyond the reach of tree roots. In the present study it is observed that highest yields have not come from

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7/ See footnote 5, p. 5.

8/ Wahlberg, H. E. "Pertinent Information on Valencia Orange Growing Over 11-year Period." The California Citrograph, p. 403. July, 1937.

the most heavily irrigated orchards, and the growers applying more than 28 inches of water per year have not done as well as more conservative irrigators; the greatest number of growers used from 20 to 24 inches of water per year, but the best average production was obtained with 24 to 28 inches of water. It would appear from this that the group using an average of 26 inches of water per year was, on the average, the most successful group.

Under this premise it is possible to determine how efficient this group was in applying water. In this intermediate climatic zone the average annual use of 26 inches of irrigation water on mature orchards over the period 1931 to 1936 represents an efficiency of about 60 to 65 percent in application of water. The remaining 35 to 40 percent must have been lost by evaporation, run-off, and percolation below the root zone. This represents the results obtained by growers who have been most successful with present methods of applying water. A reduction of these losses might be effected, judging from the fact that there are some growers who get yields as high as this group with the use of less water. Apparently there is ample opportunity for improvements in methods of application.

INFLUENCE OF SOIL TYPE ON USE OF WATER AND YIELDS

It may be observed generally that trees respond to irrigation differently on different soil types; yet, provided ample moisture is available at all times, there is no basic reason why trees of the same size should transpire more water from one soil type than from another. The explanation, at least in part, lies in the fact that irrigation and other cultural operations may be performed more efficiently on certain soils than others, and there is a tendency toward larger trees and greater returns where soil conditions are most favorable.

Porous soils require more frequent irrigations, and in them more water is lost by percolation below the root zone than is the case with the compact soils. Hence, the prevention of losses of plant nutrients by leaching is a problem where soil types are coarse. Through soils of the older types having compact subsoils, water penetrates slowly and deep percolation losses are less. However, penetration may be so slow that run-off becomes a problem, and there is a greater loss of the more fertile top soil by erosion during rainstorms as well as irrigations. In medium soil types of texture uniform to great depths, trees usually root deeper and irrigation is much easier.

Orchard soils in the San Dimas area were segregated according to these three general classes and the results are shown in table 1. Annual amounts of irrigation water applied and yields are given for each of three soil types. More water was applied to orchards on the porous soil north of red hill, but yields were not appreciably different from those of orchards located on the more compact red hill land.

Neither of these two groups yielded as well as the orchards on the deeper soils of medium type south of red hill, and the best average production, 5.7 field boxes per tree, was obtained from the orchards on the deeper soils. On the red hill land yields were 4.2 field boxes per tree, while north of the red hill a production of 4.1 field boxes per tree was obtained. Thus, a definite advantage is shown by the orchards on deep medium soils.

Table 1. - Influence of soil type on water applied to citrus orchards and effect on yields in the San Dimas area, 1931-1936

Location	Accounts	Soil type	Average yield, per tree	Average water applied, per year
	Number		Field boxes	Inches
North of Red Hill	39	Recent gravelly sandy loams in San Dimas wash area	4.1	25.2
Red Hill	40	Older weathered alluvial soil with compact subsoil	4.2	18.1
South of Red Hill	39	Deep uniform sandy loams and fine sandy loams of intermediate age	5.7	23.3

How root systems of apparently similar trees vary in different soils is shown in figures 7 and 8. The tree with the more extensive root system in a deep soil (figure 7) obviously has had a large reservoir from which to draw soil moisture. The tree shown in figure 8 with its smaller root system in a coarse soil type has had a rather limited reservoir of soil moisture. Once the soil has been thoroughly moistened, the time elapsing before irrigation is required will be much longer in one case than in the other.

INTERVALS BETWEEN IRRIGATIONS

Variations in soil type and root systems bring up problems in the distribution of water over the district served by an irrigation company. In some cases it has been possible to furnish water on demand so that the determination of each date for irrigation is a matter of choice by the grower. A fixed irrigation schedule, such as some companies have used in

the past, leaves much to be desired when there are wide variations in the irrigation needs of different orchards and no choice of intervals is offered. On the other hand, while a system through which water can be delivered on demand to any point in the district might be the most desirable it may be neither practical under existing conditions nor economical to make the necessary changes.

Since the schedules for water delivery of most companies have been established on the basis of early practices, the logical approach to a practical solution of the problem is to ascertain how well these schedules meet present water requirements of the orchard served. A survey was made during 1936 of orchards in eastern Los Angeles County to gather data on the relation of irrigation intervals to water deficits in the trees.

Before judging the results of such surveys, it should be noted that from present knowledge the best interval between irrigations for a given orchard cannot be established with any degree of exactness. Further research is needed[9/] before any definite limits may be set up for permissible water deficits in the trees, for the extent to which it is desirable to dry out the soil, or for the proportion of the root zone that needs to be irrigated. All these factors have a bearing on irrigation intervals.

The important influence of soil type on root distribution was brought out in the discussion of figures 7 and 8. Where the roots extend to a great depth and are rather sparsely distributed, water deficits in the trees build up gradually as time from irrigation increases, and the interval might be varied considerably without serious risk. Where the roots are concentrated within a shallow zone, water deficits in the trees may become extreme within a period of 4 or 5 days, and there are more chances of serious water shortage. The important need is to determine which orchards are most sensitive to water shortage and then plan to make irrigation schedules flexible enough to take care of them.

To establish how well a given schedule fits the needs of any particular orchard requires that a determination be made of the water deficits that are developed in the trees. This may be obtained readily from fruit measurements, a method which has been established for checking up on orchard irrigation needs. The method is described in United States Department of Agriculture Circular No. 426.[10/] A regular series of early morning measurements will show how the fruit and the trees are responding to the available moisture supply, and, if the rate of fruit growth decreases materially before each irrigation and then rises following irrigation, positive evidence is obtained of the water deficits occurring under current practices.

9/ Furr, J. R., and Taylor, C. A. "The Growth of Lemon Fruits in Relation to the Moisture Content of the Soil." U. S. Dept. Agr. Tech. Bull. 640, 71 pp., illus., 1938.

10/ Taylor, C. A., and Furr, J. R. "Use of Soil-Moisture and Fruit-Growth Records for Checking Irrigation Practices in Citrus Orchards." U. S. Dept. Agr. Cir. 426, 23 pp., illus., 1937.

In this study 30 trees were checked on each 10-acre block, and records taken on 74 orchards in 1936 are summarized in table 2. The majority of the orchards reported in this table have moderate to high water deficits prior to irrigations, particularly during late summer months. August and September give irrigation schedules their most critical test, because transpiration requirements are high at that time and the moisture supply must come entirely from irrigation. Under a system where trees in most of the orchards develop moderate to high water deficits on present schedules, there could be little advantage to the district as a whole in changing to a demand system of water delivery although there might be real advantages to certain individual orchardists. It would appear to be adequate if enough schedules were maintained through which water might be delivered at regular intervals but often enough to take care of the orchards requiring the most frequent irrigations.

A choice of schedules may be offered based on the period of maximum demand (June 15 to October 1). These schedules might have primary intervals of 10 days, 15 days, 20 days, or 30 days, and a selection from these should be adequate to meet the needs of most orchards. Under a system of this type each grower has the privilege of selecting the service desired at the beginning of each season, but must follow the selected schedule throughout that particular season. During more moderate weather conditions prior to June 15 and after October 1, the interval may be lengthened as less water is required by the trees. Delivery on demand may be used whenever the distributing lines are not operating at full capacity. Schedules worked out in this manner and applied to the average season are shown in figure 9. Midsummer intervals are fixed on a 10-day schedule for A, 15 days for B, 20 days for C, and 30 days for D. The proportionate increases in intervals that may be used for early spring and late fall irrigations have been established from evaporation records. A current record of evaporation from a shallow-black-pan evaporimeter showing the total cumulative evaporation since the last date of irrigation gives an excellent measure of the opportunity for transpiration and hence of the probable needs for irrigation. This method is now being used in some situations and is a valuable aid in predicting irrigation needs.

Having once selected a schedule which appears suitable for a particular orchard, the grower still has opportunity to vary conditions by using more or less water at an irrigation. In the future, it may become possible to establish the most desirable interval for each orchard more precisely than can be done with present-day methods. However, there are many factors that tend to affect the value of greater precision. Each orchard is made up of a group of trees with root systems of variable extent growing in soil of variable texture. Distribution of water over the orchards is far from uniform even under the most favorable conditions. Traffic through the orchards has compacted parts of the soil and there are extreme variations in rates of absorption of water. Hence, even after precise limits for permissible degrees of water deficit in the trees have been established, there will be various factors operating to limit the attainment of an ideal interval under practical farming conditions.

Table 2.—Effectiveness of present intervals between irrigations and of amounts of water applied at each irrigation during the season of 1936 as shown by records of water deficits in 74 orchards in eastern Los Angeles County, Calif.

Orchard	Soil type	Interval between irrigations	Amount of water applied at each irrigation	Water deficits					
				May	June	July	August	September	October
Number		Days	Acre-inches per acre						
1	Clay loam	60	5.7	---	---	Moderate	Moderate	Moderate	---
2	Gravelly sandy loam	45	5.0	---	---	---	---	---	Moderate
3	Clay loam	35	4.0	---	Moderate	Moderate	Moderate	Moderate	do
4	Loam	35	4.0	---	---	---	---	Slight	Slight
5	do	31	3.2	---	---	---	---	Moderate	---
6	Clay loam	30	2.9	Moderate	Moderate	Moderate	Moderate	do	---
7	Loam	30	5.4	---	---	Extreme	Extreme	Extreme	Moderate
8	Sandy loam	30	3.5	---	High	High	High	Moderate	do
9	Loam	30	2.9	---	No	No	No	No	---
10	do	30	3.1	---	---	---	Moderate	Extreme	Extreme
11	do	30	3.6	---	---	---	---	---	Moderate
12	Sandy loam	30	3.3	---	---	---	---	Moderate	High
13	do	30	3.3	No	No	Moderate	Moderate	---	---
14	do	30	4.3	---	---	---	---	---	Moderate
15	Gravelly sandy loam	30	3.1	---	---	---	---	---	do
16	Stony sandy loam	30	2.4	Moderate	High	High	High	---	---
17	Fine sandy loam	30	3.3	---	---	---	Extreme	Extreme	Extreme
18	Loam	30	2.6	---	---	---	---	do	do
19	Gravelly sandy loam	30	3.7	---	---	---	---	Moderate	Moderate
20	Sandy loam	30	4.4	---	---	---	---	do	High
21	Gravelly sandy loam	30	2.6	---	---	---	---	High	do
22	do	30	2.9	---	---	---	---	Extreme	do
23	do	30	3.6	---	---	---	---	Moderate	Moderate
24	Loam	30	2.2	Slight	Moderate	Moderate	Moderate	---	---
25	do	30	2.2	do	Slight	Slight	Slight	Slight	---
26	Gravelly sandy loam	30	4.1	---	---	---	---	do	Slight
27	do	30	4.5	---	---	---	---	Moderate	Moderate
28	Clay loam	30	4.0	Slight	Slight	Slight	Slight	High	---
29	Fine sandy loam	30	2.7	---	---	---	---	do	---
30	Sandy loam	30	4.0	---	Slight	Slight	Moderate	---	---
31	Loam	30	3.2	---	---	---	---	Moderate	Moderate
32	Gravelly sandy loam	30	---	Moderate	Moderate	Moderate	Moderate	---	---
33	Sandy loam	30	4.1	---	---	---	---	Slight	Slight
34	Loam	30	---	---	---	High	High	High	Moderate
35	do	30	4.0	No	No	Moderate	Moderate	Moderate	---
36	gravelly sandy loam	30	---	---	---	---	---	High	High
37	Sandy loam	30	3.4	---	---	---	---	Moderate	Moderate
38	do	30	3.4	---	---	---	Moderate	High	---
39	Gravelly sandy loam	30	3.2	---	---	---	---	Moderate	Moderate
40	Loam	30	2.5	---	---	---	---	Extreme	do
41	do	30	2.5	---	---	---	---	High	do
42	do	30	---	---	Slight	Slight	Moderate	Moderate	High
43	Gravelly sandy loam	30	3.2	---	---	---	---	---	Moderate
44	do	30	4.3	---	---	---	---	High	---
45	Sandy loam	30	3.8	---	---	---	High	do	High
46	do	30	3.8	---	---	Extreme	do	do	Moderate
47	do	30	1.9	---	---	do	Extreme	Extreme	Extreme
48	do	30	4.0	---	---	---	---	Slight	Slight
49	Gravelly sandy loam	28	4.9	Moderate	Moderate	High	High	High	---
50	Stony sandy loam	26	---	---	do	do	do	Moderate	---
51	do	25	3.2	Slight	Slight	Moderate	High	---	---
52	Sandy loam	22	3.4	---	---	---	---	Moderate	Moderate
53	Stony sandy loam	22	1.7	Moderate	Moderate	High	High	---	---
54	Gravelly sandy loam	22	2.9	---	---	---	---	---	Moderate
55	Clay loam	21	4.0	---	---	---	---	High	do
56	Sandy loam	21	2.3	---	---	Moderate	Moderate	Moderate	do
57	Stony sandy loam	20	2.5	Moderate	High	High	High	High	---
58	Gravelly sandy loam	20	---	No	No	Moderate	Moderate	do	---
59	do	20	2.7	High	Extreme	Extreme	Extreme	---	---
60	do	20	2.9	---	---	---	---	---	Moderate
61	Stony sandy loam	20	2.6	Moderate	High	Extreme	Extreme	---	---
62	Sandy loam	20	1.8	---	---	High	High	Extreme	Extreme
63	Gravelly sandy loam	15	2.3	---	Moderate	do	Extreme	Extreme	---
64	do	15	3.4	---	---	Slight	Slight	Slight	Slight
65	Sandy loam	15	---	---	---	---	Moderate	Moderate	Moderate
66	Stony sandy loam	15	---	No	Moderate	Moderate	Moderate	Moderate	---
67	Gravelly sandy loam	15	3.5	Moderate	do	High	High	High	---
68	do	15	4.0	---	---	Moderate	do	Moderate	---
69	do	15	4.0	---	---	do	Moderate	do	---
70	Loam	15	1.8	---	---	High	High	High	Moderate
71	Sandy loam	15	2.2	---	---	Moderate	Moderate	Moderate	do
72	Gravelly sandy loam	15	3.3	---	---	---	---	Slight	Slight
73	Stony sandy loam	10	.7	Slight	Slight	High	High	High	---
74	Light gravelly sandy loam	10	1.4	No	do	Slight	Slight	Slight	---

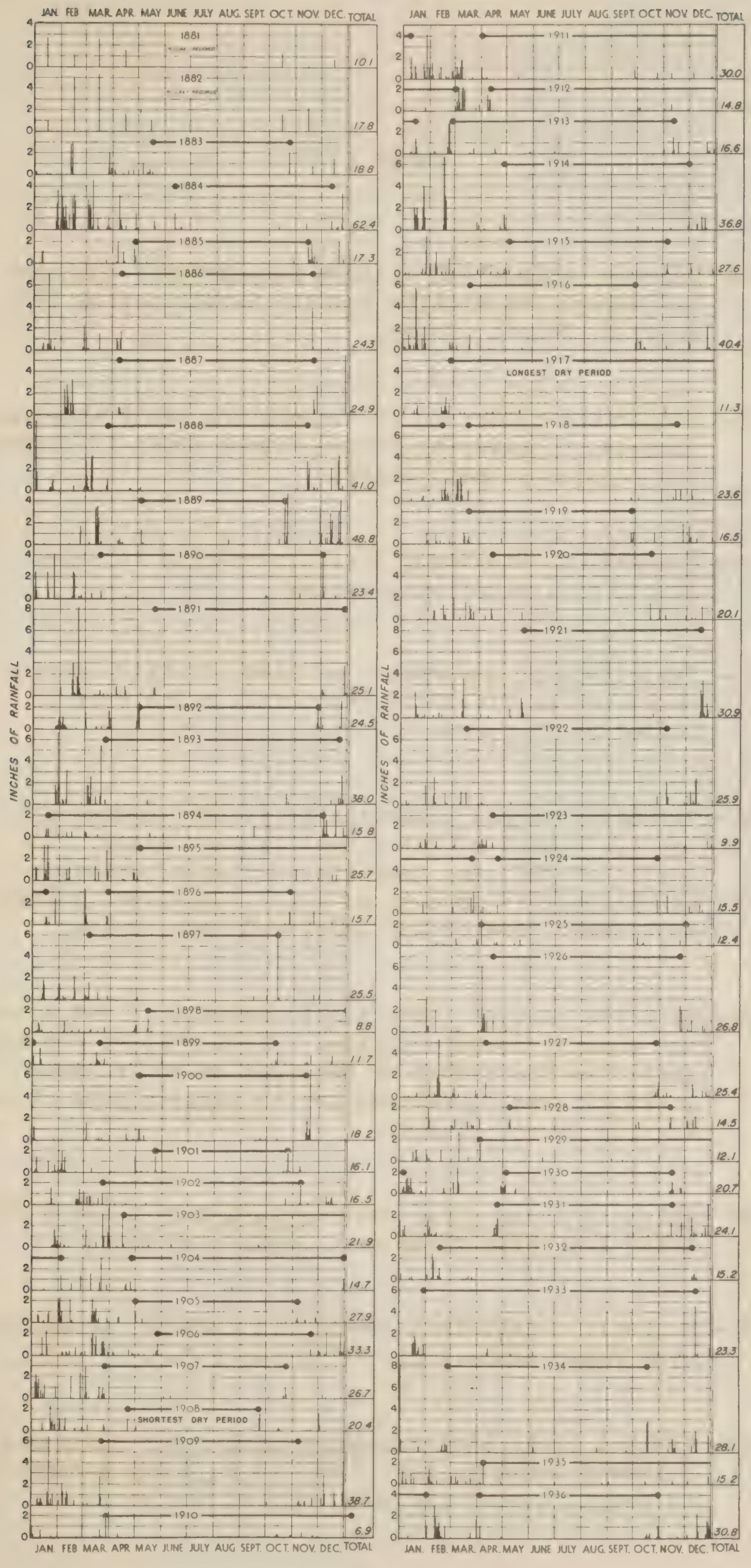
Figure 3

RAINFALL

GLENDORA, CALIFORNIA

1881-1936

MEAN ANNUAL - 23 INCHES



GROUP I

Figure 1-- Average maximum and minimum temperatures compared to average evaporation for the 5-year period 1932 to 1936, Pomona, Calif.

Figure 2-- Comparison of trends of evaporation and transpiration-use of water by mature citrus trees in eastern Los Angeles County, Calif.

Figure 3-- Rainfall at Glendora, Calif., arranged to show length of irrigation seasons.

Figure 4-- Variations in occurrence of last effective spring rains and of first effective fall rains over a period of 55 years.

Figure 5-- Orchards grouped according to yields showing the average amount of water used by each group. The height of the bars indicates number of orchards using specific amounts of water. Orchards located in eastern part of Los Angeles County, Calif.

Figure 6-- Orchards grouped according to amounts of water used and showing average yields. The height of the bars indicates the number of orchards in the various yield classes. Orchards are in eastern part of Los Angeles County, Calif.

Figure 7-- Valencia orange tree growing in a deep uniform fine sandy loam with roots at a depth of 9 feet.

Figure 8-- Valencia orange tree growing in a stony, sandy loam with roots concentrated in upper 3 feet of soil.

Figure 9-- Typical irrigation schedules with water furnished on selected schedule during the average dry season and on demand during the remainder of the year.

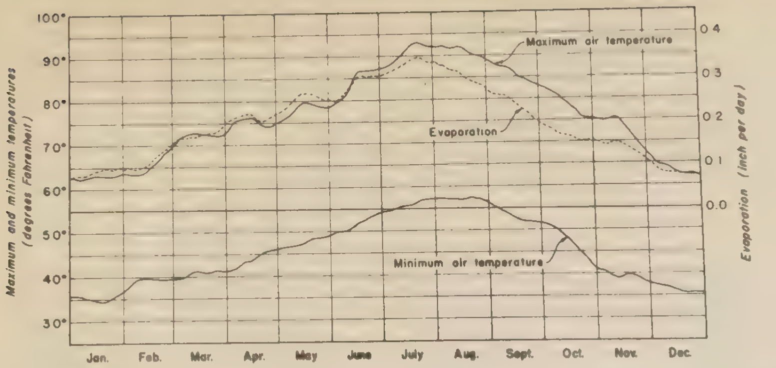


FIGURE 1 — Average maximum and minimum temperatures compared to evaporation for the five-year period 1932-1936, Pomona, Calif.

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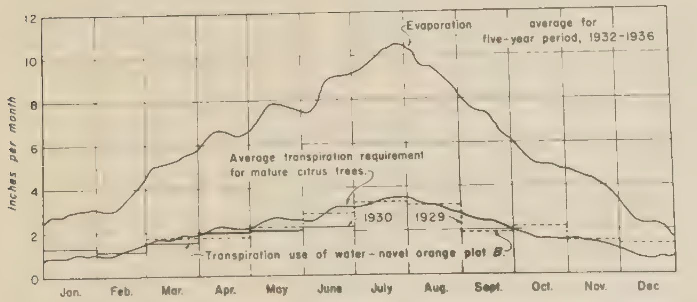


FIGURE 2 — Comparison of trends of evaporation and transpiration-use of water by mature citrus trees in eastern Los Angeles County, California.

2

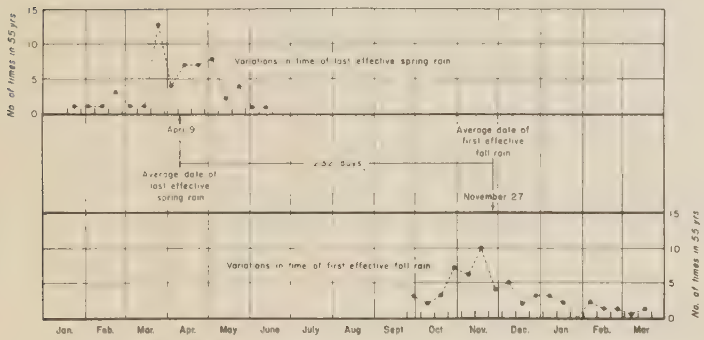
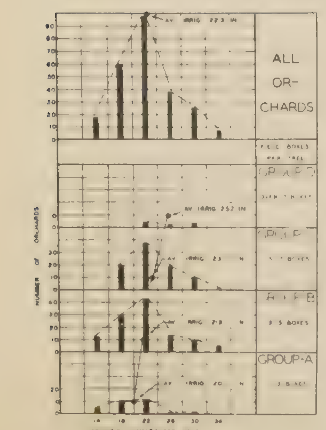


FIGURE 4 — Variations in occurrence of last effective spring rains and of first effective fall rains over a period of 55 years

4



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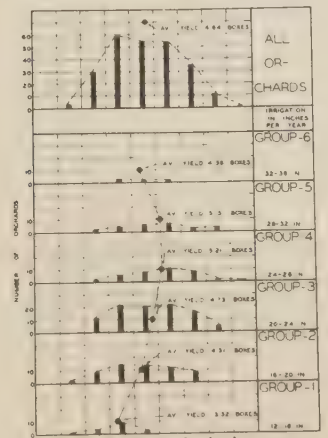

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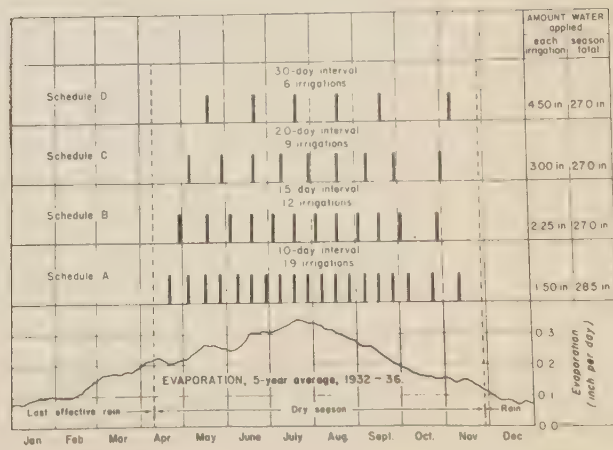

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PLOW SOLE OR COMPACTED SOIL AND ITS EFFECT ON THE ABSORPTION OF WATER

The problem of distributing water uniformly to a block of orchard trees is greatly complicated by variations in absorption rates. Even though the soil structure may be fairly uniform when the trees are set out, cultivation and traffic through the orchard alter its ability to absorb water. When the soil is dry, it can sustain relatively heavy loads and be cultivated without damage but movement of tools and vehicles over wet soil compresses it. The compacted soil just below the depth of cultivation is commonly referred to as plow sole. Continued cultivation and traffic finally develop a compacted layer below the depth of cultivation strong enough to sustain the loads it is required to bear. Some parts of the soil are affected more than others. In mature orchards traffic tends to be centered midway between tree rows and the compacted layer of soil may be dense enough to inhibit root growth. This is illustrated in figure 10, which shows the layer to be most compact in the area between trees where most of the furrows are ordinarily located. The rate at which water infiltrates downward into the root zone is affected by the density and thickness of this compacted layer. The effect of this plow sole layer has been discussed in an earlier paper[11] in which it was shown that furrows in the plow sole area absorb water only one-third as fast as where the soil has not been compacted. The present survey was made to determine the depth to which soils in citrus orchards have been compacted and the general extent of the compacted soil conditions.

For this survey a measure of density was obtained by recording the energy necessary to drive a standard sampling tube into the soil. Density of the compacted zone was compared with density of undisturbed soil under the spread of the tree within 3 feet of the trunk. In mature citrus orchards the soil along the tree line close to the trunk is seldom reached by cultivating tools and has no traffic over it. Hence, tests in that area were used as control holes and served as a basis for measuring the relative compactness of the soil which was cultivated and had to bear traffic.

A summary of the results of tests made in February and March 1937 is given in the diagrams of figure 11. The diagrams show the number of blows from a 10-pound hammer required to drive a sampling tube 0.3 of a foot downward into the soil. The hammer was dropped through a distance of 1 foot. Tests were made to a depth of 18 inches and values were recorded for each successive increment of 0.3 foot. In each case the record for the undisturbed soil near the trunk of the tree is given in the left-hand column and that for the compacted soil in the right-hand column. The separations into groups A, B, and C were made on the basis of the structure of the undisturbed soil at the control stations. Group A represents tests in friable soils with loose structure; group B is intermediate; and group C represents tests in firm soils with tight structure.

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[11] Taylor, C. A., "Water Penetration in Hardpan Citrus Soils," Agr. Engin., Vol. 15 (6), pp. 202-203, illus., 1934.

The softer soils with the least stable original structure, group A, have been altered more at greater depth than those in groups B and C, but all have been compacted to a noticeable degree.

Over 3,500 tests were made in 52 orchards, and the soil was found to be compacted to varying degrees in all orchards. It is evident from figure 10 and the diagrams in figure 11 that the compaction extends to a considerable depth. The greatest degree of compaction was found at a depth of 7 to 11 inches below the soil surface, but some effect was noted at 18 inches. Cultivation of the soil too soon after irrigation is responsible for much of the plow sole, but compaction at the lower depths was most probably due to the movement of heavily loaded vehicles through the orchards.

Because of the depth of the plow sole, the most practical way to improve conditions is by the use of cover crops that send their roots down through the compacted layer. Organic matter applied as manure, while helpful in improving the physical condition of the top soil is not as beneficial for correcting plow sole as a well-rooted cover crop. Cultivation should always be deferred until the soil is relatively dry, and heavy traffic should be reduced to a minimum and confined to definite lanes.

Too many farmers permit heavily loaded manure trucks in their orchards when the soil is wet from winter rains. Dairy manure is often purchased at a stated price, "spread in the orchard," and the damage to the soil structure when the soil is wet may outweigh the benefits from the manure. Organic matter in the soil makes conditions favorable for the activity of beneficial soil organisms and helps maintain the soil in good physical condition to absorb water. Careful managers will not permit these benefits to be off set by unnecessary traffic over moist soil.

Previous tests showed that compaction interfered with and restricted the downward movement of moisture. Variations in rates of infiltration of water comparable to the variations in compaction are shown in the measurements of water absorption reported in the following pages.

VARIATIONS IN ABSORPTION OF WATER UNDER FURROW IRRIGATION

Many growers who have planted orchards on new lands have observed a lessening of the ability of the soil to absorb water after it has been farmed for a number of years. At first a flow of water for irrigation must be divided among only a few furrows, but as the orchard matures the same flow must be divided between a much greater number of furrows because rates of absorption have decreased. The greatest decreases have been within the plow sole or compacted parts of the soil. As the trees increase in size, traffic tends to center midway between tree rows; and, when furrows are placed under the spread of the branches, the inside or tree furrows absorb water much faster than the furrows in the center traffic lanes.

Measurements were made in 16 orchards in 1936 to obtain an indication of the extent of the variations in absorption rates in different furrows. Small calibrated V-notch weirs were set in furrows at various points, and the absorption of water along the furrows between weirs was ascertained. The necessary calculations were then made to convert the readings into equivalent inches of depth over the area served by each furrow. Samples of results are given in figures 12, 13, and 14. A study of these figures indicates why the general average efficiency of furrow irrigation is relatively low. Extreme variations were found in all orchards where the tests were made. It is difficult to secure a uniform wetting of the soil when infiltration rates vary in this way, and frequent tests with a probe or a soil tube are necessary to demonstrate that adequate penetration is secured without waste of water. Because of the labor involved, few orchards are checked in this manner. It is much easier to apply more water for a longer time until a few general tests show that a good penetration has been secured. When this is done more water is applied to some parts of the orchards than is actually required. Again, it is noted that overirrigation troubles may develop when there is leaching with excessive amounts of water and yields may be affected.

In an orchard in which the amount of water applied is relatively low, it is inevitable that parts of the soil get too dry from time to time and production may be reduced. The charts in figure 6 show that average production was definitely low for the groups using the least amounts of water; yet some growers, who have used better than average care in distributing water over their orchards, have obtained good production with sparing amounts of water. Best average production was attained by the group using 26 inches per year, but for the groups using still larger amounts, the average yield was less. Overcoming variations in absorption requires skillful handling of the water by the irrigator, and it is not entirely solved by simply running water in all furrows for long periods of time. One of the most important opportunities for advancement in present practices lies in improving distribution of water over the orchard.

EFFECTS OF IRREGULAR DISTRIBUTION OF WATER

From a consideration of the material submitted thus far, variations in the production from different parts of each orchard might be expected to appear because of the varied water supply. However, data bearing on this question are difficult to obtain because production records are not ordinarily kept for individual trees and the fruit on a tree is not all picked at one time. A few records were secured, but they were not extensive enough to be useful in showing variations related to water supply. Another method of examination involves determining whether size of fruit at harvest time has been affected by variation in irrigation practices, and this method proved to be most feasible for the purpose in mind.

In the discussion of Transpiration Requirements and Climatic Influences, it was noted that winter rains usually leave the soil filled to field capacity at the end of the rainy season. The trees

have this reserve supply of moisture to draw on during the spring and early summer, and shortages because of poor irrigation practices are usually not severe until late summer. Except on very light soil types, most growers are able to avoid serious water shortages during the fruit setting period. Under present practices the most severe water deficits occur in August and September. (See table 2.) Therefore, it would seem reasonable to expect that after the crop has set, the effects of poor irrigation during the season will be reflected in fruit sizes at harvest time. While the system of measuring fruit sizes was selected for use, the method does not take into account effects that carry over from year to year and cause cumulative differences in size of trees and set of fruit. Thomas[12] reported studies on the irrigation of citrus orchards in 1922, concluding that, "Citrus trees growing on heavy soil may become stunted when excessively irrigated, the leaves turn more or less yellow and many of them fall prematurely. The yield of fruit is also greatly impaired and in some instances the trees may become unprofitable." Observations of these cumulative effects are not reported in the present study. However, overirrigation leaches soluble plant food below the root zone, and a deficiency, especially of nitrates, would tend to cause a poor set of fruit. For a complete analysis it would be essential to have both size and total yields, but individual tree-yield records could not be obtained in sufficient numbers for the purpose.

Records were obtained during the orange harvest season of 1936, and measurements of the size of fruit produced on each tree were made in certain orchards. After a detailed investigation of various methods of sampling, it was decided that 10 fruits would be measured on each tree. The measurements were then averaged and plotted to scale and the plotted records examined to determine which sections of the orchard produced fruit above or below average size. Each row of trees was examined particularly for evidence of decreasing size of fruit as distance from pipe line increased. Records were obtained and analyzed in this manner for over 25,000 trees in 35 orchards in the eastern part of Los Angeles County. There were 17 navel orange orchards and 18 Valencia orange orchards in the study, and a total of 256,780 fruits were measured. A summary chart of the records from one of the orchards is given in figure 15. The furrows are a little over 500 feet long in this orchard, and fruit sizes were found to decrease as distance from pipe line increased until a point was reached 380 feet away from the pipe line. The last 6 trees in this orchard were "cross-blocked" so that extra water was ponded along the tree lines. The effect of this added water appears in sizes of fruit on the end trees.

Many of the orchards had two or more pipe lines, and each block of trees served by a separate line was considered as a separate unit. Thus, 60 blocks were examined, and in 38 blocks no definite decrease in sizes away from pipe lines could be detected. The remaining 22, or slightly less than 37 percent of the total number, showed definite trends toward smaller sizes as distance from pipe line increased.

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[12] Thomas, E. E., "Studies on the Irrigation of Citrus Groves," Calif. Agr. Expt. Sta. Bull. 341, pp. 353-370, March, 1922.

GROUP II

Figure 10-- Soil profile in a Valencia orange orchard showing compacted soil in traffic lane midway between tree rows.

Figure 11-- Plow sole conditions in eastern Los Angeles County, Calif., as measured by the energy required to drive a standard sampling tube into the ground. Values are numbers of blows from a 10-pound hammer dropped through a distance of 1 foot.

Figure 12-- Variations in absorption of water from furrows-- Orchard A.

Figure 13-- Variations in absorption of water from furrows-- Orchard B.

Figure 14-- Variations in absorption of water from furrows-- Orchard C.

Figure 15-- Summary graph showing the variation of fruit sizes as regards distance from pipe line. Orchard C, Pomona, Calif., 1936 harvest.

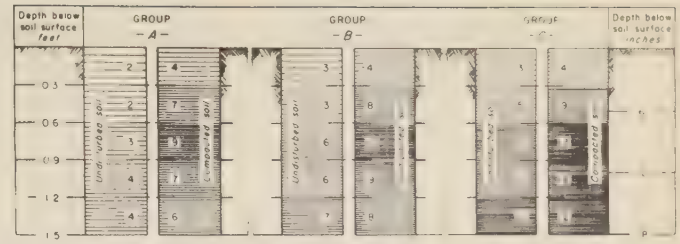


FIGURE — Plow sole conditions in eastern Los Angeles County, California as measured by the energy required to drive a standard soil tube into the ground. Values are number of blows from a ten-pound hammer dropped through a distance of one foot

-11-

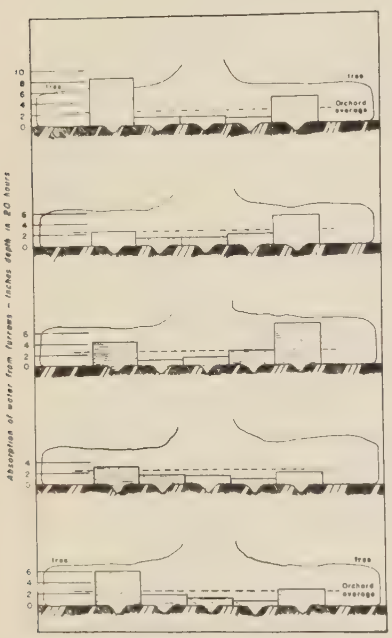


FIGURE — Variations in absorption of water from furrows — Orchard A

-12-

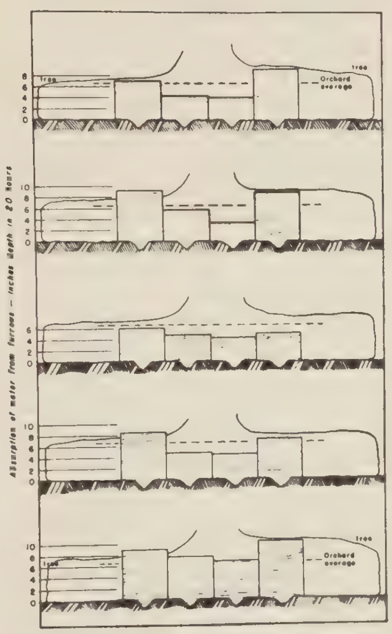


FIGURE — Variations in absorption of water from furrows — Orchard B

-13-

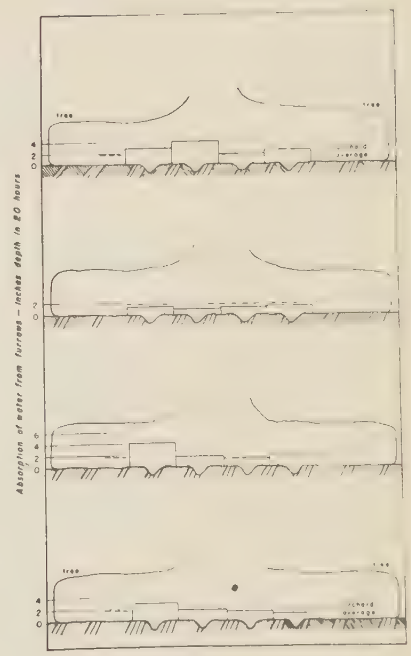
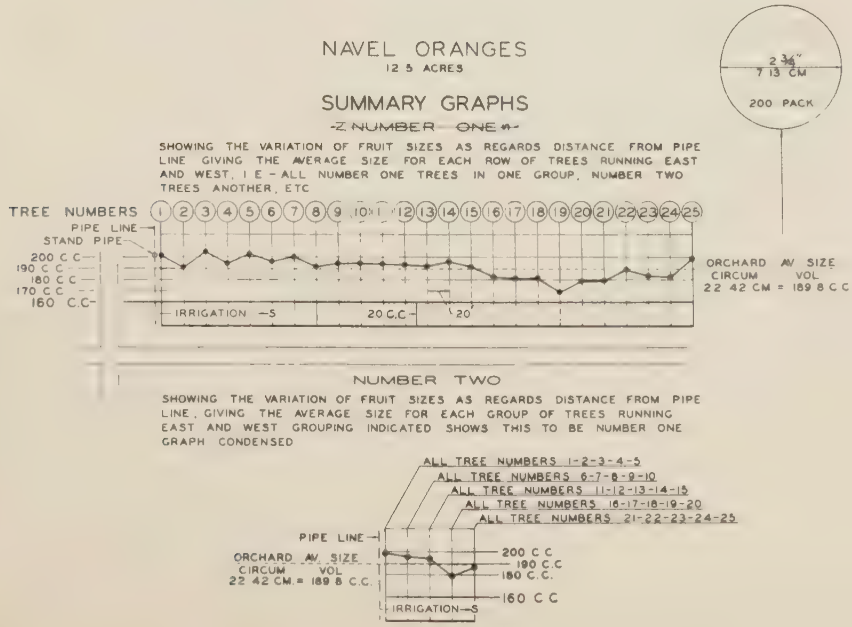


FIGURE — Variations in absorption of water from furrows — Orchard C

-14-



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These are listed in table 3, giving the length of furrows and the percent decrease in size of fruit along the rows. Either more pipe lines or better methods of distributing water along the tree rows are needed in some of these orchards.

Table 3. - Effect of length of irrigation furrows on fruit sizes in 22 orange orchards in eastern Los Angeles County, Calif., irrigation season of 1935, fruit picked in spring of 1936

Orchard	Soil type	Length of furrows	Trees in row	Decrease in fruit sizes along row	Remarks
Number		Feet	Number	Percent	
1	Gravelly sandy loam	270	13	5.3	Cross furrows at every tree
2	Do	291	14	4.1	Do
3	Sandy loam	313	15	8.5	Do
4	Gravelly sandy loam	486	25	12.6	Cross blocks last 5 trees
5	Sandy loam	446	21	9.3	Cross blocks lower end
6	Fine sandy loam	306	16	16.8	Do
7	Sandy loam	276	14	4.3	Cross blocks last 6 trees
8	Gravelly sandy loam	226	12	22.6	Straight furrows; no blocks
9	Do	246	13	6.0	Do
10	Loam	325	17	9.8	Cross blocks lower end
11	Clay loam	182	9	3.6	Straight furrows; no blocks
12	Do	225	11	11.4	Do
13	Sandy loam	294	14	4.8	Cross blocks last 6 trees
14	Do	269	13	8.4	Do
15	Gravelly clay loam	225	11	2.3	Cross blocks last 4 trees
16	Sandy loam	360	18	4.7	Cross blocks at every tree
17	Gravelly clay loam	444	23	5.8	Straight furrows; no blocks
18	Do	365	19	5.3	Do
19	Gravelly sandy loam	946	40	6.5	Cross blocks at lower end
20	Do	204	10	8.1	Do
21	Gravelly loam	402	19	3.9	Cross blocks last 3 trees
22	Sandy loam	204	10	9.4	Straight furrows; no blocks

In the majority of the orchards, however, the average size of fruit did not vary significantly along the rows away from pipe lines. Apparently variations in water supply were not great enough to cause measurable differences in sizes. Hence, the addition of more pipe lines in these orchards to decrease the length of furrows is not justified from this evidence alone.

It appears that rather large differences in irrigation practices may exist without causing measurable differences in fruit sizes. However, the argument might be advanced that since reasonably uniform sizes are obtained, despite the present irregular distribution of water, savings in water can be effected by irrigation methods that permit a more even distribution throughout the orchard. Then deep percolation losses might be avoided and the average use of water lowered.

Figure 5 indicates that top production was obtained from some orchards on which the use of water was considerably less than the general average for the district. That fact, together with those relative to length of furrows and fruit sizes, indicates that trees will maintain good production as long as the net transpiration requirements are satisfied in this area where the quality of irrigation water is exceptionally good and there is ample winter rainfall. Where more saline waters are used some additional water must be applied for the purpose of leaching away undesirable salts. Under present conditions in this area excess waters now applied may be saved if practical means are available for obtaining a more uniform distribution of water throughout the orchards. Relative advantages of different methods are discussed in later paragraphs.

IMPROVED IRRIGATION PRACTICES

The furrow method of irrigating has been used most widely for orchard work. The origin of this method is somewhat obscure, although it probably developed from the use of the plow for making furrows. From this start with the plow, there has been a gradual development in furrowing machinery. Tools in common use consist of shovels or disk blades attached to carrier frames by means of standards or shanks. These implements make furrows that are relatively narrow and deep, and a number of objections may be cited against them. If water is flushed through the furrows when first turned on, there is an excessive movement of loose material along the bottoms of the furrows. Flow of water through narrow, sharp furrows is usually made turbulent by rocks and small clods, and with a turbulent flow more erosion occurs. There is undercutting of the sides, and eroded material which falls into the water is carried away. With a deep, narrow channel, the load carried by the water is generally not deposited until it reaches the end of the furrow, and there is a loss of valuable top soil from the orchard. Erosion may be reduced if the flow is cut down, but water then advances down the furrows very slowly. When the surface soil is air dry, wick action draws away appreciable quantities of water on both sides of the slowly advancing stream. So much time is consumed before water reaches the ends of furrows that absorption and penetration near the upper ends are much greater than farther along the furrows. A large amount of water is lost by deep percolation near the upper ends of furrows.

Turbulent flow with erosion in narrow furrows is illustrated in figure 16.

With the usual system of straight-furrow irrigation in orchards, a strip of soil along the tree line is left unirrigated. After moisture from spring rains is used up, part of the root system remains inactive until rains occur during the following winter. When attempts are made to reduce the width of this unirrigated strip, furrows may be placed so close to the trunks of the trees that lateral roots may be injured or cut off entirely by implements. Both disk blades and the common type of furrowing shovel are inherently objectionable in this respect. Many citrus trees when pulled have shown that the main lateral roots had suffered serious injury from tillage implements. Where old roots had been severed, only a few feeble rootlets had grown out in replacement. After an old root is cut, new growth does not develop with the same vigor that characterizes new shoots after pruning.

In order to reach more of the soil along the tree lines, cross-furrows are sometimes used where the slope of the land is favorable, but this entails added labor and expense and the straight-furrow system is used more widely. Therefore, in investigations of orchard irrigation problems conducted by the Division of Irrigation, special study has been made of straight-furrow irrigation methods.

The use of narrow furrows has persisted, although early workers recognized that wide furrows gave better penetration than narrow ones. However, the early experiments in irrigation were interpreted as indicating that deep furrows and a loose surface mulch were essential in order to avoid excessive losses by evaporation. At that time it was believed that there was an upward flow of capillary moisture that could be broken by cultivation. Experiments by McLaughlin in 1915 demonstrated that, in the absence of a water table, the upward movement of capillary water was very limited in extent. This demonstration and further work by Veihmeyer proved that the idea behind cultivation for the purpose of conserving moisture was false. Stirring of the top soil was shown to have no influence on evaporation losses, and therefore cultivation could be limited to that which was necessary for the control of weeds. In the light of present knowledge, it is clear that orchard soils should be disturbed as little as possible.

For many years the value of wide furrows was lost sight of because of the urge for deep and thorough cultivation. Broad furrows were used to some extent, however, in the sandy soils south and east of Ontario, California, about 1920, and later in Ventura County, near Oxnard. When made in sand, deep furrows tend to "sugar down" while the water is running, and after a short time a fairly wide base develops in the furrows. This led to the practice of making furrows broad to start with, and V-crowders made from 2-inch planks were used to form them. Elsewhere various efforts have been made to perform the necessary orchard tillage operations with a minimum disturbance of the soil.

Work in the Bureau of Agricultural Engineering was directed at first towards adaptation of the shank-type implements that were in most general use. Side slopes of furrows were reduced and a method for control of weeds in permanent furrows was worked out and has since been used in a number of commercial orchards. Permanent furrows were kept

clear of weeds by the use of furrowing sweeps (figure 17) which were drawn through the furrows. The soil is disturbed very little by these sweeps, but in order to cut the weeds satisfactorily they must not be permitted to grow for more than one irrigation interval in many situations. Frequent cultivation for weed control leaves loose soil in the bottoms of these furrows and there is a tendency for this soil to be carried to the lower ends of the irrigation runs. Means for overcoming this movement were sought and tests were made with wide flat-bottomed furrows in order to determine the extent to which they could be adapted for general use. Furrows of this type are illustrated in figures 18 and 19. Equipment developed for making broad shallow furrows is shown in figures 20, 21, 22, 23, and 24. Essential features in figure 24 are the curved blades set at the proper angle to pick up a shallow layer of soil and move it sidewise, so making the parallel ridges which border intervening broad shallow furrows. The cutting edges of the blades normally run about 2 inches below the average ground surface, and the cutting depth may be even less if the orchard is properly "leveled" to an even grade. Thus the necessary working depth of these tools is considerably less than that required for cutting under the winter cover crop with a disk harrow, and, with this advantage gained, furrows can be made closer to the trees with less danger of disturbing roots.

The various types of broad-furrow equipment illustrated have all been designed to perform the necessary furrowing operations with the least possible working depth. Depth of soil disturbed need not be greater than 2 inches, but in order to make full use of this feature, cultivation with cover-crop disks must also be kept as shallow as possible. In general, permitting weed growth to mature during the summer is questionable practice, although it may be necessary in special cases. Whatever gain there may be in organic matter tends to be offset by the disking operations which prevent roots from growing into the disturbed soil. After the winter cover crop has been turned under, weeds should be kept under control so that further heavy disking is avoided. Depth of summer and fall cultivations should not be greater than that required for furrowing tools which need not be more than 2 inches when broad-furrow equipment is used.

With adequate equipment available for making broad shallow furrows, orchard cultivation and irrigation practices can be brought more closely in line with fundamental principles. Instead of gouging a deep, narrow furrow into the root zone, an effective water-conducting channel is made with the disturbance of a minimum depth of soil. More of the fertile top soil can be made available for the roots. With water spread over more of the soil surface, it becomes more effective in moving soluble plant nutrients into the root zone. Flow along the smooth wide furrows is less turbulent, and water may be conducted to the lower ends of the furrows in less time and with less erosion. Fewer furrows are required, and hence less labor for regulating the flow. Repeated irrigations may be applied in the same wide furrows with less clogging from leaves and trash. Cover crops can be started more readily, because it is easier to keep more of the top soil moist, and effective light irrigations can be applied. The cover grows in the bottoms of the furrows where it is more effective in retarding erosion and improving penetration. When it is

Figs. 16-21

GROUP III

Figure 16-- Turbulent flow in a narrow furrow. Note undercutting of sides.

Figure 17-- Furrowing sweeps used for control of weeds in permanent furrows.

Figure 18-- Wetted outline in broad shallow furrows.

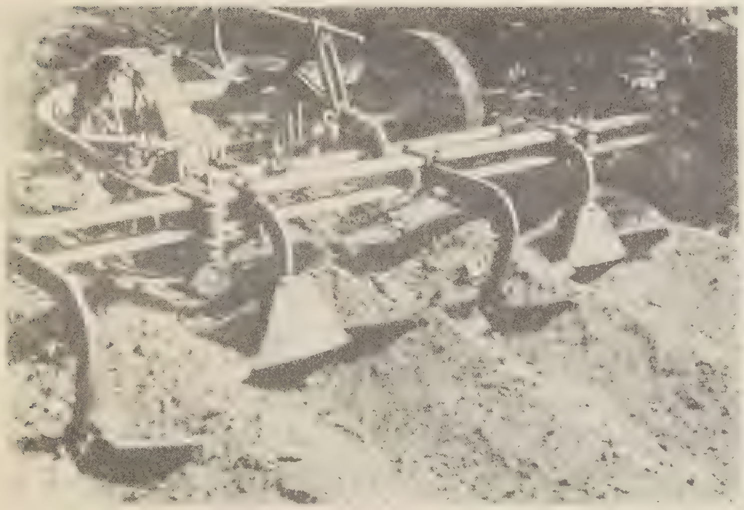
Figure 19-- Wetted outline in broad shallow furrows.

Figure 20-- Equipment for making broad furrows. Low-cost 2-furrow unit of the drag type trailing behind an offset disk harrow.

Figure 21-- Equipment for making broad furrows. Two, 2-furrow units of the drag type trailing behind a spring-tooth harrow.

16

19



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necessary to leach out toxic accumulations of salts, broad furrows are advantageous. Plants extract the water from the soil solution and leave much of the salt residue to accumulate within the root zone.[13] If this salt residue is not displaced downward by rain, removal by irrigation may become necessary. With wide furrows there is less tendency for a building up of salts midway between furrows. By alternating the position of furrows and ridges at subsequent irrigations, effective leaching can be accomplished and injurious salts washed out. However, when injurious salts must be leached, it should be remembered that soluble plant nutrients go also, and it may be necessary to add nitrates after a thorough leaching.

Thus there are many advantages from using broad shallow furrows, and growers who have tried this method have found it to be an improvement over old methods and have continued its use. The best water distribution is obtained with broad furrows on land with little or no cross slope. When the land has considerable cross slope, water tends to run against the downhill side of the furrows so that the entire furrow bottom may not be covered with water. Nevertheless, broad-furrow machines have been used on contoured hillsides and the furrows proved advantageous because of shallower cultivation, less choking from weeds, less breaking over, and better cover crops. Broad-furrow irrigation is pictured in figures 25, 26, and 27.

The problem of distributing water in furrows requires that special attention be given furrows next to the trees. Tree furrows absorb water readily in most cases and many growers equalize the distribution along the orchard row by diverting water from center furrows into tree furrows at one or more points along the row. This is usually necessary when broad furrows are used on extra long runs. A convenient method of making these diversions is illustrated in figure 28. Thus a long ridge of soil juts out into the center of the stream to be divided, and the division holds its set because the water is turned gradually and is not checked in velocity. Abrupt turnouts or divisions from furrows usually fail quickly either because of the silting up of one side or the other or by cutting away of the soil on one side of the division point. Where small gravel is available, it can be used to advantage in making divisions. It is of considerable help where the water must be taken from the pipe line through one gate and then divided among several furrows. Many irrigators keep a small supply of pea gravel at the head of each row.

For the most profitable management of mature orchards, it usually becomes necessary to adopt a definite program for replacing weak, diseased, or unprofitable trees. The care of young trees replanted in mature orchards is a special problem. Young replants can not develop properly under the same irrigation and cultivation schedule on which the large trees are maintained. A certain amount of extra hand labor is required around each replant for several years after it is set out. Because more sunlight reaches the area around small trees, weeds grow

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13/ Scofield, Carl S., "The Effect of Absorption by Plants on the Concentration of the Soil Solution," Jour. Agric. Res. 35 (8): 745-756, 1927.

Figs. 22-27

GROUP IV

Figure 22-- Equipment for making broad furrows. 4-furrow, folding wing unit with hydraulic depth control.

Figure 23-- Equipment for making broad furrows. 4-furrow unit with cross-blocking attachments.

Figure 24-- Equipment for making broad furrows. Folding wing lifted to show blade design.

Figure 25-- Broad-furrow irrigation in an orchard where there is no cross-slope.

Figure 26-- Broad-furrow irrigation in a contour planting. The soil is heavy and the grade steep.

Figure 27-- Broad-furrow irrigation in an orchard on coarse stony soil.


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rapidly and soon offer serious competition for fertilizer and water. Weeds should be hoed down until the trees develop sufficiently to shade out the growth around the trunks of the trees. The winter cover crop should be watched carefully in late February and March and hand work around the young trees started before the regular spring cover-crop disking. The small trees should be given every opportunity to push out during the spring flush of growth when growing conditions are most favorable.

For the irrigation of small trees, basins may be employed for two or three years. Water is carried to the young trees in tank wagons during the first year, and after that definite amounts of water may be turned in from adjacent furrows. Basins or short lengths of extra furrows should be made so that water does not stand around the trunks of the trees in order to lessen the danger of infections from brown rot gummosis. For the first three years the regular irrigation furrows should not be run close to the trunks of the young trees nor water left in them for the full regular irrigation time allotted for the large trees. If water is left too long around the young trees, all the soluble plant nutrients will be washed down beyond the reach of their roots. Broad furrows have a special value for applying frequent light irrigations around the young trees.

As illustrated in figure 15, cross-blocking of the furrows at lower ends of long rows improved fruit sizes on the trees near the ends of the rows. As long as care is taken to avoid ponding too much water, cross-blocking at the lower end may be used to take care of minor fluctuations in flow. Then run-off from some furrows and drying back of others may be avoided. Some soil types take water slowly and water must be kept in furrows for 12 hours or more. There is then a problem of fluctuations in rate of entry of water into the soil throughout the day owing to temperature changes and an evaporation effect. In some tests made at Pomona in 1937, it was found that certain furrows absorbed 10 percent more water at 2 p.m. than at 5 a.m. Water temperatures near the ends of furrows varied from 60 degrees in the early morning to 95 degrees at 2 p.m. and tests have proved that warm water is absorbed more readily than cool water. Under practical farming conditions, when the soil takes water slowly, it is necessary to allow for 10 percent run-off to take care of evaporation and the effect of temperature changes or else make continuous adjustments of the flow. The latter process adds to the labor cost so that allowance for the run-off may give the best economy.

Cross-blocking along the tree lines at the ends of rows is practical where the cross-slope of the land is negligible. In some cases it becomes advisable to cross-block the entire orchard. For example, there are cases where so much soil has been washed away that lateral roots are at the ground surface and straight furrows can not be made close enough to the trees for adequate irrigation. The system of cross-blocking, illustrated in figure 29, is similar to that used in walnut orchards. When the orchard is laid out in this manner, cross furrows are made first. Then the implement with blocking attachments is used and the tree furrows are cross-blocked in the direction water

is to flow. The irrigator directs the flow so that it zig zags back and forth along the tree line in the cross furrows. Usually the upper third of the row is irrigated with water turned in at the head of the row. Water is carried down center furrows and diverted into the cross-blocked furrows at one-third and two-thirds of the distance along the row. This lay-out leaves the two center or lead furrows available for traffic through the orchard.

The lay-out just described is also an effective method for control of winter rains. Cover crops are started readily as the entire surface soil can be moistened quickly with a light irrigation. However, straight furrows are in more general use, and, while cover crops can be started readily in straight furrows of the broad shallow type, there is usually some run-off from winter rains in the center furrows because of their compacted condition. Run-off from the center furrows may be diverted into the tree furrows at several points along the tree rows where it is absorbed more readily. Thus run-off from the orchard is avoided in normal rains and kept under control during excessive storms. It is well to keep the furrows open and not pond too much water within the orchard during exceptionally heavy precipitation. After the root zone is thoroughly moistened, nothing is gained by water-logging the soil with excess water. Some damage occurred in 1914 and 1916 because basins were formed and left in the orchards during those excessively wet winters. A well-established cover crop in broad furrows affords adequate protection to the soil even when there is general run-off. Figures 30 and 31 illustrate cover crops developed under cross-blocked and straight-furrow systems.

On steep hillsides where erosion may be a serious problem, portable low-head sprinklers are used to advantage. This method of irrigation is illustrated in figure 32. Portable pipe lines with quick-acting couplings are available in sizes suitable for orchard use. Three or more sprinklers are used on each portable unit and each sprinkler head is intended to throw water within the space cornered by four trees. The units are shifted by dragging them endwise through the orchard, or by uncoupling the pipe and carrying the sections to the next set. Better distribution of water to each tree and lower cost makes this system more desirable than a permanent sprinkler installation throwing water over the tops of the trees.

With the broad-furrow method of cultivation, illustrated in figure 21, it is not necessary to disturb the soil more than 2 inches deep. Hence, broad furrows can be laid out in sprinkler-irrigated orchards at low cost. They are an advantage for the control of run-off both from winter rains and from the sprinklers, as is illustrated in figure 33. With broad furrows, run-off water does not travel far, as the movement of water in thin sheets is very slow. When this factor is taken into account, the design of the sprinkler lay-out can be more economical. Some hillside orchards can be farmed best with a more or less permanent cover crop that is mowed from time to time. This practice is used in the orchard shown in figure 33. Cover may be left in alternate rows as

Figs. 28-33

GROUP V

Figure 28-- Method of dividing water in furrows.

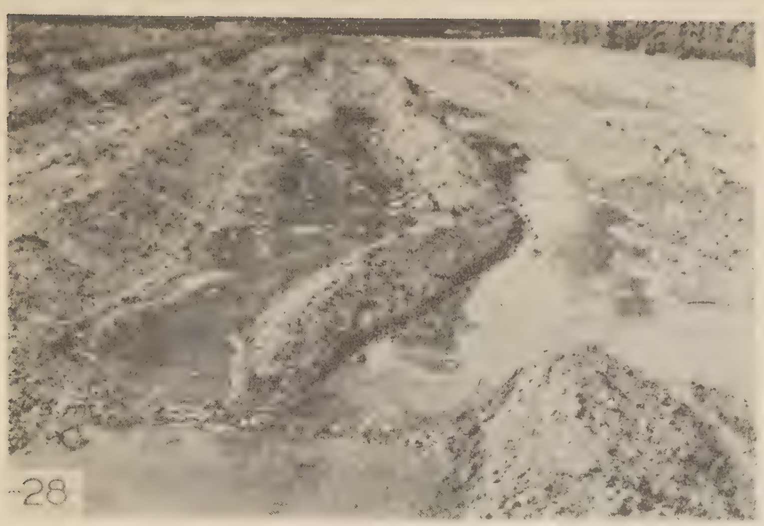
Figure 29-- Orchard laid out with cross furrows along the tree lines. Cross connections had not been made when this picture was taken.

Figure 30 -- Winter cover crop in an orchard with cross-blocked furrows. Note provision for traffic through the orchard with this lay-out.

Figure 31-- Volunteer winter cover crop in broad shallow furrows.

Figure 32-- Irrigation with portable low-head sprinklers.

Figure 33-- Sprinkler-irrigated orchard with broad furrows for control of run-off.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noted by Huberty and Brown[14]. This is an economical method where summer cover crops are used as it enables the grower to keep an adequate supply of moisture for the tree in the clean-cultivated middles even though the cover may dry out the soil on one side of the trees more or less completely. Cover crops use water, and moisture conditions must be watched more carefully when there is a cover. When water is to be applied in alternate middles the flexibility of low-head units is a definite advantage.

While alternate-middle irrigation has been used through the entire season in a few situations, it has a more general application for irrigations that are applied during the cooler months of the year. It is not necessary to wet the entire root zone when the transpiration demand is low and then alternate-furrow or alternate-middle irrigation may be used and some economy in operation effected. Water may be applied as indicated in figure 34 so that it reaches one-half of the roots of each tree and leaves the remaining half unirrigated. Water is cross-transferred readily throughout the tree so that the entire tree will receive a supply of moisture when one-half the root zone is irrigated[15]. While this is true of the movement of water within the tree, it should not be inferred that mineral nutrients travel in a similar manner. Nutrients from the soil appear to travel in rather definite paths from main roots to main branches; hence, when fertilizer is applied it should be broadcast on all sides of the tree.

The main purpose of alternate-furrow or alternate-middle irrigation is to distribute a relatively small amount of water over the orchard to better advantage. It offers some opportunity for improving efficiency in the application of water and attaining the maximum economy in operation. The greatest opportunity for advancement over present methods appears to be in better distribution of water within the orchard. Both broad furrows and low-head sprinklers are advantageous in this respect.

For a small orchard, the investment for broad-furrow equipment, shown in figure 21, need not be more than $35. Cost of operation, for four cultivations and refurrowings during the season, need not be more than $4 per acre when only one trip per row is required for cultivating and furrowing as shown in figure 21. If the spring disking costs $2 per acre, then the total annual cost of operation for cultivating and furrowing need not be more than $6 per acre. Operation costs are less where orchards have been laid out in uniform blocks and proper space has been allotted for turning at the ends of rows. In some cases, the spring disking and necessary cultivations and refurrowings have been carried out with operation costs as low as $4 per acre per year. The general average cost for the industry as a whole has been much higher, and, in most cases, operation costs can be reduced when the broad-furrow method of cultivation is adopted.

14/ Huberty, M. R., and Brown, J. E., "Irrigation of Orchards by Contour Furrows." Calif. Agr. Expt. Sta. Cir. 16, 16 pp., illus., 1928.

15/ Furr, J. R., and Taylor, C. A., "The Cross-Transfer of Water in Mature Lemon Trees." Amer. Soc. Hort. Sci. Proc. (1933) 30:45-51, illus.

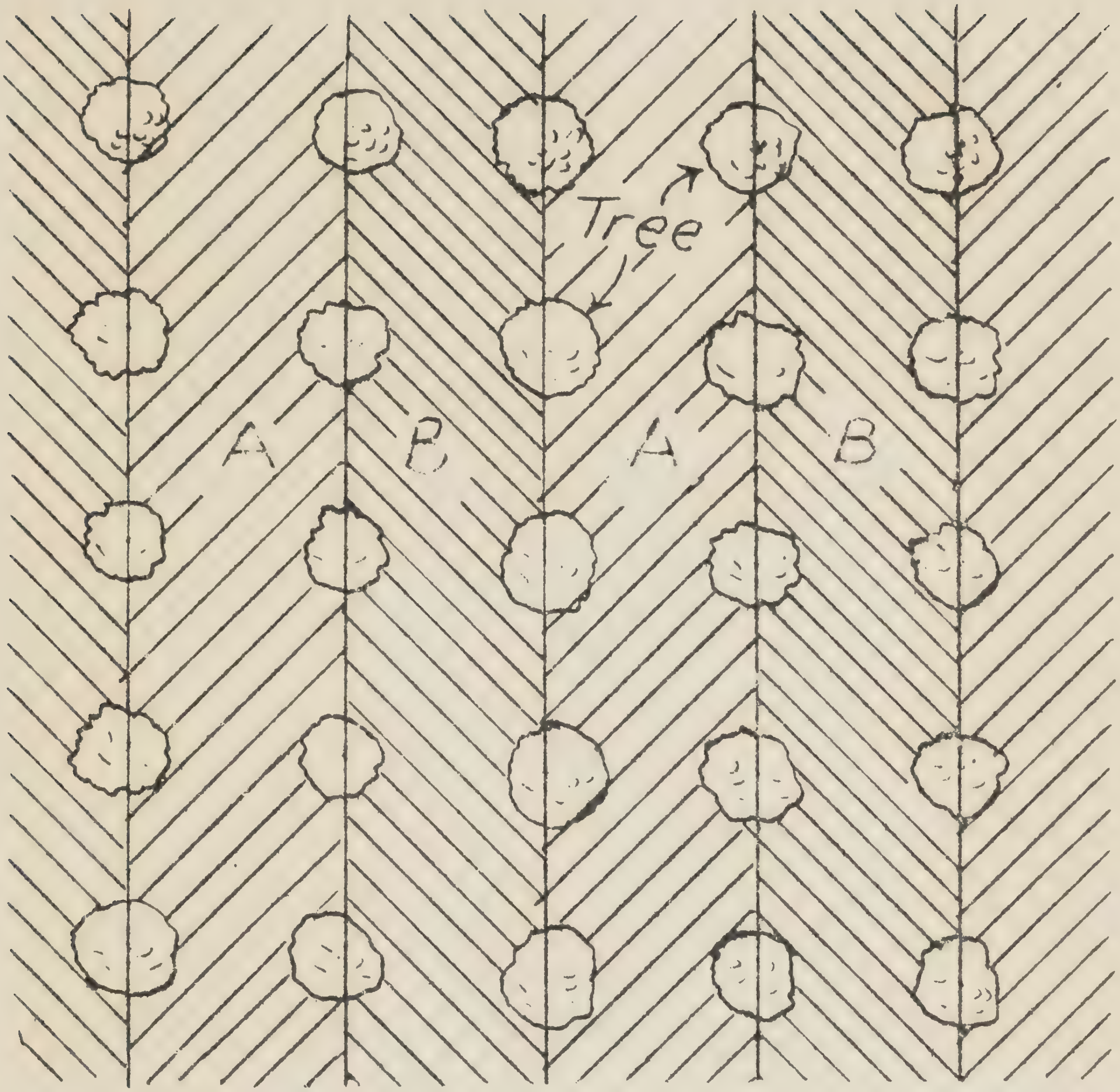

Figure 34 - Alternate middle irrigation. "A" middles irrigated while "B" middles left dry; at the next irrigation the "B" middles are irrigated and the "A" middles left dry.

Along with economies in cash costs of operation, there are other savings that result from improved methods. Those who make the best use of their soil will disturb it the least and use its fertility to the maximum advantage. This means, also, that adequate moisture is maintained in the root zone and that water is spread evenly over the orchard without unnecessary leaching. When this is given the attention it merits, the problem of overirrigation is one of small consequence.

Irrigators find that water must be handled in a somewhat different manner in broad furrows than when narrow ones are used. A larger flow is used in each furrow and water reaches the ends of broad furrows in less time. It is absorbed at higher rates since there is more water in contact with soil, and, therefore, the time required for each set is less. With proper adjustment, water reaches the lower ends of broad furrows in a very thin sheet and hence its velocity at the lower end is very low. Some study is required with the broad-furrow system if full advantages are to be secured. When making changes in irrigation practices, growers will find it profitable to use means for checking up on soil moisture and fruit growth as described in United States Department of Agriculture Circular No. 426[16/].

In many situations soil-moisture control has been tried where the irrigation methods were so erratic that the attempted control was of doubtful value. In most cases, it is essential to correct the manner of water distribution first. Thereafter, methods for soil-moisture control and for determining the best irrigation interval can be used to real advantage.

16/ See footnote 10/, p. 9.